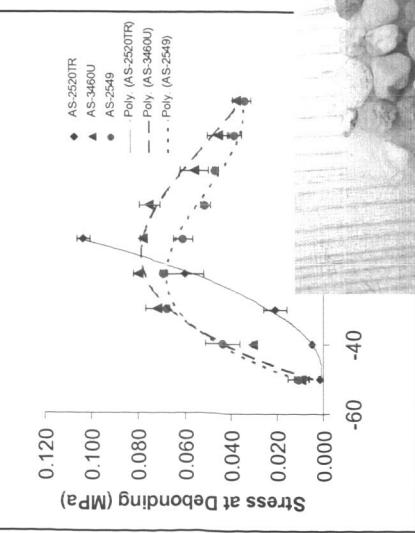




**SPACEWORKS**



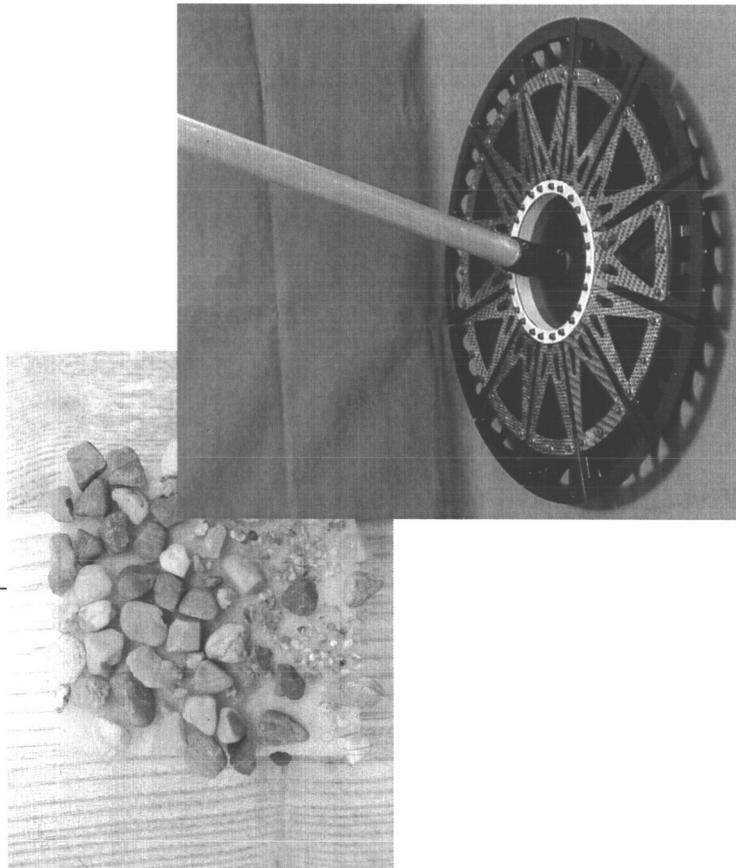
# Surface Sampling System For Low-Gravity Missions

Final Project Report

September 8, 2005

Prepared for:  
NASA  
Goddard Space Flight Center  
Greenbelt, MD 20771  
Contract NAG5-13150

Prepared by:  
SpaceWorks, Inc.  
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Carefree, AZ 85377-2014



# **Surface Sampling System**

## **Background**

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**SpaceWorks began collaboration with Dr. Derek Sears on the Hera mission in March 2000**

- Preparation for possible submittal as a Discovery mission proposal
- Worked with Dr. Sears and others on the technical concept
- Provided recommendations on programmatic issues

**In mid 2000, Dr. Sears elected to postpone submittal of proposal until the following Discovery competition**

- Re-evaluate technical and programmatic approaches
- Conduct work on key technical challenges

**University of Arkansas (UArk), Honeybee Robotics, and SpaceWorks collaborated on development and demonstration of the “Touch and Go Sampler” for possible application to the Hera mission**

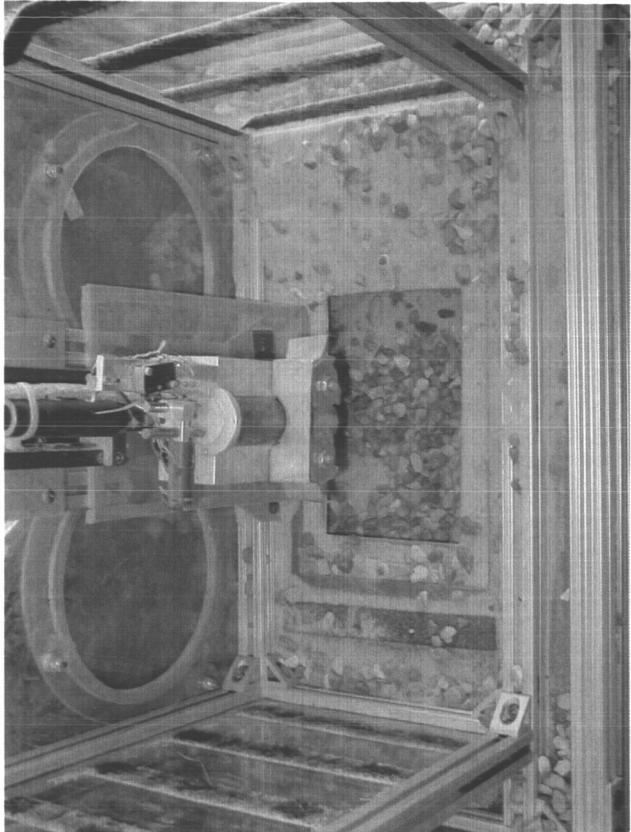
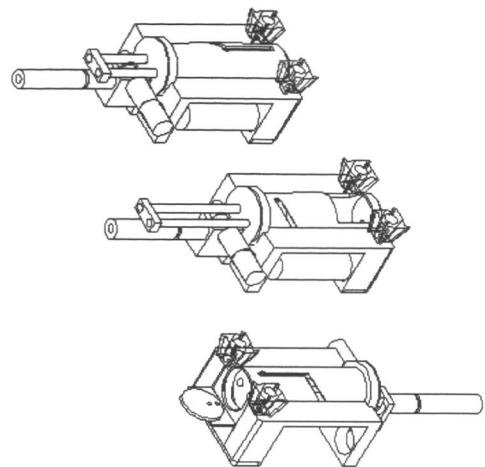
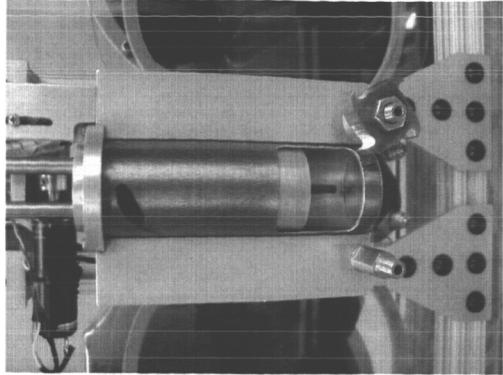
- Sampler, controller, and enclosure completed by team in early 2001
- Conducted limited set of ground tests
- Conducted two flight tests on the Reduced Gravity Program KC-135 on September 26 and 27, 2001
- Conducted a more extensive set of ground tests following the KC-135 flights at UArk

# **Surface Sampling System**

## **“Touch and Go Sampler”**

### **Touch and Go Sampler Concept**

- Counter-rotating bits collect material from sample surface and direct it toward sample chamber
- Sample material is collected in chamber, isolated, and stored



# Surface Sampling System

## September 2001 KC-135 Test Results

### Sample Collection

- Test equipment could accommodate 48 samples during the two flight tests
- Collected 13 samples

### Sample Material

- Attempted collection using gravel, cement, sand, and sand+iron samples
- Collected gravel (6 of 13 samples), cement (6 of 13 samples), and sand+iron (1 of 13 samples)

### Collected Mass

- Maximum collected mass: 9.034 g
- Minimum non-zero collected mass: 0.021 g
- Average sample mass: 1.468 g
- Median sample mass: 0.422 g

Material	Day	Parabola Number	# of Chips	Mass (g)
Gravel	1		5	9.034
Gravel	1		7	3.356
Gravel	1		10	1
Gravel	1		17	1
Gravel	1		19	1
Cement	2		1	0.879
Cement	2		8	0.422
Cement	2		9	0.483
Cement	2		1	0.041
Gravel	2		12	1
Cement	2		11	1
Cement	2		9	0.026
Sand+iron				2.708
Average				1.468
Median				0.422

# **Surface Sampling System**

## ***Conclusions From September 2001 Flight Test***

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### **Observations**

- Very little sample material was collected - concept is not able to meet 100 g requirement
- Rotating bits launched sample material at unnecessarily high velocity toward chamber
- There was no concept for capturing sample in chamber if it entered
- Small, moving parts were very susceptible to damage and jamming
- Approach would provide no data on surface particle location, orientation, or distribution and could alter particle itself
- This concept was not appropriate for collecting material from a small body like an asteroid, comet, or moon

### **Recommendations**

- Reduce or eliminate moving parts
- Eliminate exposed parts that move relative to one another with tight tolerances
- Consider means to trap sampled material once it is removed from surface
- Reduce or eliminate the use of magnetic materials
- Reduce energy applied to surface material (be gentle)
- Find means to retain information on location, orientation, and distribution of particles on surface (goal)
- Find means to ensure that mechanical properties of individual particles are not altered (goal)



# Surface Sampling System

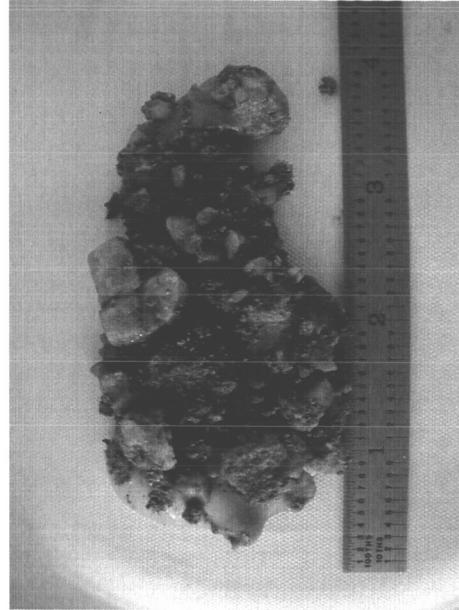
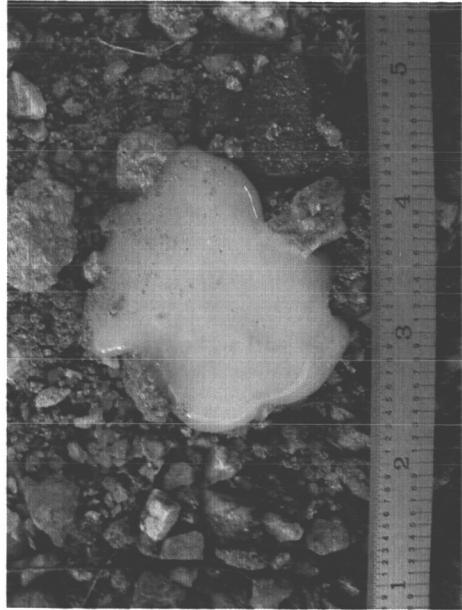
## New Sampling System

- Following the flight test, SpaceWorks examined alternative approaches for collecting surface samples

- Scoops, Traps, Projectiles, Drills, etc.

**Focused work on an adhesive-based sampling system targeted on missions to bodies with unconsolidated material that is lightly held to surface (asteroids, comets, moons, etc.)**

- Adhesive is applied to the surface of a conformable pad at the end of boom
- Could address all of limitations found during earlier flight test
- Could be designed to meet goals of retaining data on surface properties by taking an intact slab of surface material



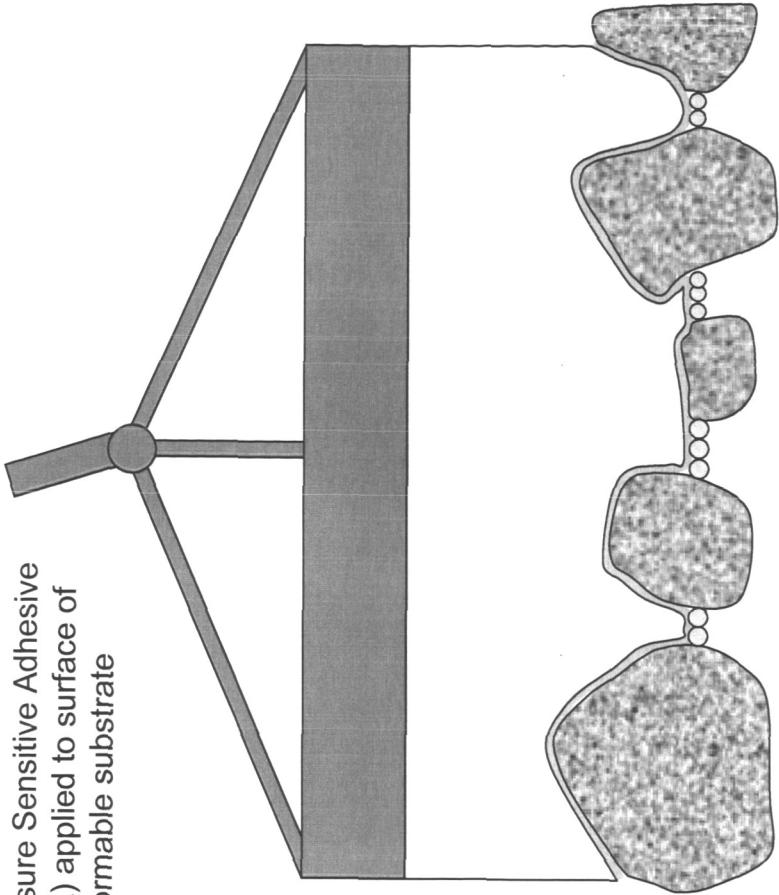
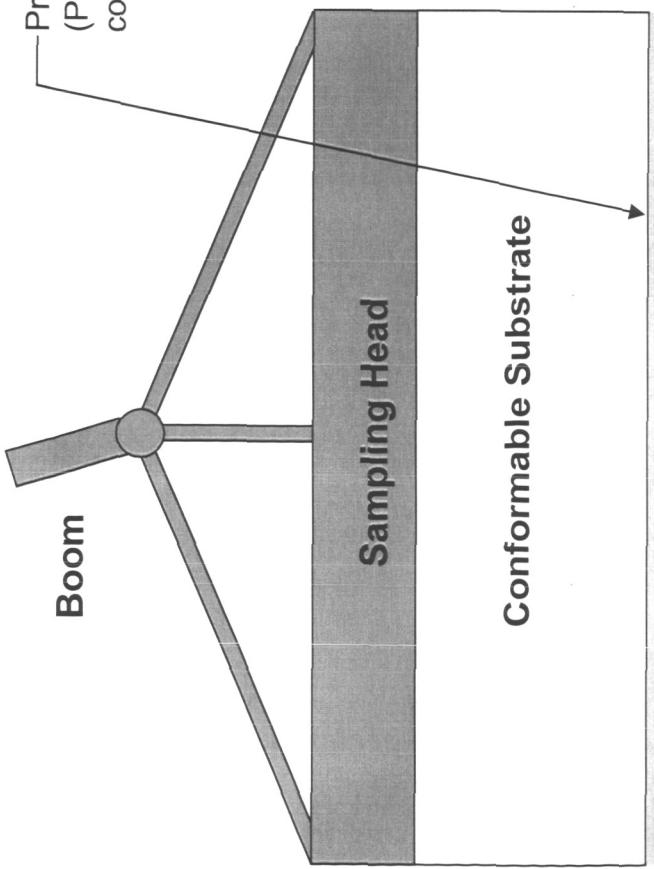
## Submitted proposal to Research Opportunities in Space Science (ROSS) 2002

- Selected in December 2002
- Awarded contract in April 2003

**Mass**  
After Sampling: 52 g  
Before Sampling: 12 g  
Sample: 40 g

# Surface Sampling System

## Surface Sampling Concept



### Primary Advantages:

- Minimizes disturbance to surface
- Collects everything that it touches
- Retains mechanical properties of surface particles
- Retains location, orientation, and distribution of surface material
- Passive system reduces demands on spacecraft

# **Surface Sampling System**

## **Project Summary**

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- Title:** Surface Sampling System for Low Gravity Missions
- Issuing Agency:** National Aeronautics and Space Administration
- Issuing Office:** Goddard Space Flight Center  
Code 214.4  
Greenbelt, MD 20771
- Contract No.:** NAG5-13150
- Contract Type:** Firm Fixed Price
- Date of Award:** April 1, 2003
- Period of Performance:** 24 months (through March 31, 2005)
- Team Members:** University of Arkansas (Dr. Derek Sears - science)  
Virginia Tech University (Dr. Timothy Long - adhesive development)
- Objectives:**
- A. Identify Candidate Missions
  - B. Define Requirements
  - C. Conduct Deployment Mechanism Trade Study, Design, and Demonstration
  - D. Conduct Adhesive Trade Study, Design, and Demonstration
  - E. Conduct Substrate Trade Study, Design, and Demonstration
  - F. Design and Demonstrate Integrated Unit

# Surface Sampling System

## Project Objectives (1 of 3)

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### Eight project objectives were identified in the original proposal

- Identify missions involving surface sampling and define requirements
  - Identify several candidate missions that can benefit from an efficient, low mass, low cost surface sampling system
  - Accumulate the requirements for each of the sampling systems
    - Identify the key requirements that are common throughout these missions
- Define the detailed requirements for an asteroid surface sampling system, document requirements, and flowdown to system elements
  - Select asteroid sample return mission as the target mission
  - Identify requirements for an asteroid surface sampler system
  - Document detailed requirements and flowdown to sampling mechanism, sampling pad, and spacecraft
- Perform trade study of candidate deployment mechanisms and select one or more candidates for detailed design, development, and documentation
  - Identify 3-5 candidate mechanisms capable of meeting the requirements allocated to the deployment mechanism
  - Perform trade study
  - Select baseline deployment mechanism for design, development, and demonstration



# **Surface Sampling System**

## **Project Objectives (2 of 3)**

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- Design, develop, and demonstrate one or more key elements of the deployment mechanism
  - Complete detailed design of the deployment mechanism including provisions for attachment and jettison of sampling pad, repeated stowing/deployment, and efficient design for transferring pad to sample return capsule
  - Identify one or more key elements of the deployment mechanism for development and documentation
  - Procure, fabricate, assemble, and demonstrate one or more key elements of the deployment system
- Trade study of candidate pressure sensitive adhesive (PSA) for asteroid surface sampling and selection of one or more PSA systems
  - Identify and design polyurethane segmented block copolymer and/or acrylic based PSA compositions based on literature and current programs at Virginia Tech
  - Evaluate PSA strengths using peel strength mechanical measurements
  - Identify optimum composition based on rheology, thermal properties, and mechanical performance
- Synthesis and characterization of tailored PSA
  - Synthesis of segmented polyurethane block copolymers
  - Synthesis of acrylic random copolymers
  - Evaluation of adhesive and rheological performance based on compositional variation
  - Determination of the sampling efficiency versus composition relationship

# **Surface Sampling System**

## **Project Objectives (3 of 3)**

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- Design, development, and demonstration of PSA impregnated conformable sampling pad
  - Develop suitable pad geometries based on solution and melt casting to planar and fibrous surfaces
  - Evaluation of fiber spinning process with particular attention on electrospinning for increased surface area
  - Determine the optimum conformable pad geometry for particular sampling
- Design, development, and demonstration of integrated mechanism/sampling pad
  - Based on the results of the previous hardware work completed on the mechanism and sampling pad, design, integrated mechanism/sampling pad that demonstrated key elements of operation and interfaces
  - Fabricate and assemble integrated mechanism/sampling pad
  - Demonstrate operation of integrated unit

# **Surface Sampling System**

## *Project Tasks*

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**Eight tasks were developed to address the project objectives identified in the proposal**

- Identification of sampling missions
- Definition of requirements for an asteroid surface sampling system
- Trade study of deployment mechanism
- Demonstration of deployment mechanism
- Trade study of candidate PSAs
- Synthesis and characterization of tailored PSAs
- Demonstration of conformable sampling pad
- Demonstration of integrated mechanism/sampling pad

## **Surface Sampling System**

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### *Identification of Sampling Missions*

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#### **SpaceWorks reviewed various microgravity sampling missions**

- The following missions are the most applicable to SpaceWorks sampling system

ID	MISSION
1	South Pole Aitken Basin Sample Return Mission
2	Comet Surface Sample Return
3	Asteroid Rover/Sample Return
4	Comet Nucleus Surface Sample Return
5	Mars Sample Return
6	Comet Surface Sample Return-Samples from a Selected Surface Site

# Surface Sampling System

## Requirements For An Asteroid Surface Sampling System (1 of 3)

ID	Requirement Title	Requirement
1	Sample	The sampling subsystem shall be capable of collecting and retrieving sample material from an asteroid, comet, moon, or other space object.
2	Number of Space Objects	The sampling subsystem shall be capable of collecting and retrieving sample material from a minimum of 3 different space objects.
3	Sample Events at Each Space Object	The sampling subsystem shall be capable of conducting a minimum of 3 sample events at each space object.
4	Sampling Efficiency	The sampling subsystem efficiency shall be a minimum of 50% when measured as the sample area of the sample pad covered by sample material as compared to the total sample pad area.
5	Sample Return	The sampling subsystem shall deliver the sample material to a sample return capsule.
6	Sampling Subsystem Standoff Distance	The sampling subsystem shall be capable of collecting and retrieving sample material from the target surface with a separation distance of 2 to 30 m between the spacecraft and target surface.
7	In-track Relative Velocity	The sampling subsystem shall be capable of collecting and retrieving sample material with a relative velocity of $0 \pm 1$ cm/s between the spacecraft and the target surface in the direction of travel.
8	Cross-track Relative Velocity	The sampling subsystem shall be capable of collecting and retrieving sample material with a relative velocity of $0 \pm 1$ cm/s between the spacecraft and the target surface perpendicular to the direction of travel.
9	Vertical Velocity	The sampling subsystem shall be capable of collecting and retrieving sample material with a relative velocity of $10 +1/-9$ cm/s between the spacecraft and the target surface normal to the surface.
10	Particle Size	The sampling subsystem shall collect and retrieve particles that are powder-sized to 2 cm in diameter.

# Surface Sampling System

## Requirements For An Asteroid Surface Sampling System (2 of 3)

ID	Requirement Title	Requirement
11	Surface Properties	The sampling subsystem shall collect sample material in a way that preserves the location and orientation of the sample material as it was on the target surface prior to sampling (peel up slab).
12	Particle Discrimination	The sampling subsystem shall collect sample material that is representative of the target surface (not favoring a particle size or type).
13	Sample Material Mechanical Properties	The sampling subsystem shall collect and retrieve sample material in a way that does not mechanically alter the sample material.
14	Sample Material Chemistry	The sampling subsystem shall collect and retrieve sample material in a way that does not alter the chemistry of the sample material.
15	Sampling Safety	To minimize risk to the spacecraft, the sampling subsystem shall not create high velocity particles.
16	Disturbance Torques	The sampling subsystem shall collect and retrieve sample material in a way that does not impart torques or moments greater than 160 N-m on the spacecraft.
17	Sampling Impulse	The sampling subsystem shall not impart an impulse on the spacecraft greater than 160 N-s.
18	Lifetime	The sampling subsystem shall be capable of operation in a near-earth space environment for a period no less than 10 years (for reference only: 2.0 years out, 0.5 at asteroid, 2.0 years back to Earth, 2.0 years out, 0.5 years at asteroid, 2.0 years back to Earth, and 1 year for margin) after launch.
19	Pre-Launch Storage	The sampling subsystem shall be capable of storage in a suitable environment for a minimum of one year prior to launch.
20	Mass	The sampling subsystem mass shall not exceed 5 kg.

# **Surface Sampling System**

## **Requirements For An Asteroid Surface Sampling System (3 of 3)**

ID	Requirement Title	Requirement
21	Nominal Power Consumption	The sampling subsystem nominal power consumption shall not exceed 10 W.
22	Peak Power Consumption	During sampling events, the sampling subsystem peak power consumption shall not exceed 10 W for longer than 60 s.
23	Envelope	The sampling subsystem shall be completely contained within the volume(s) allocated on the spacecraft.
24	Sample Collection Depth	As a goal, the sampling subsystem shall be capable of collecting and retrieving sample material from a depth of 1 cm below the target surface.
25	Motor-Driven Elements	As a goal, the sampling subsystem shall not contain any motor-driven elements within the sampling head.
26	Electrical Harnessing	As a goal, the sampling subsystem shall not require electrical harnessing along the length of the boom to the sampling head.
27	Retrieved Sample Mass Estimate	As a goal, the sampling subsystem shall be able to estimate the mass of the retrieved sample material.

# Surface Sampling System

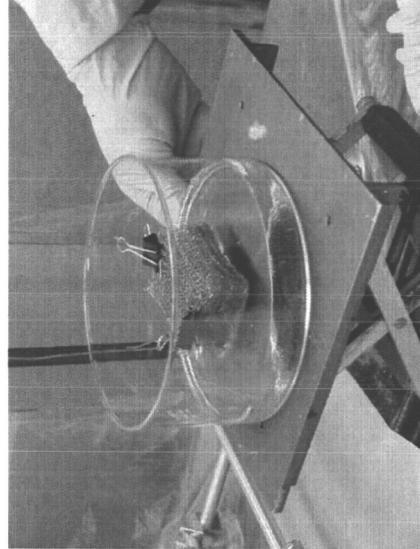
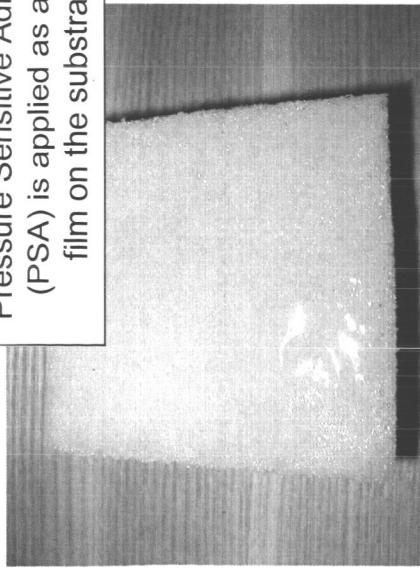
## Adhesive

### Key Requirements

- The adhesive operational temperature range shall be as wide as practical
- The adhesive shall have a TML of 1.0% or less, and a CVCM of 0.1% or less
- The adhesive shall be able to perform in a space environment for no less than 10 years
- The adhesive shall be able to be applied to complex surfaces
- The adhesive shall not alter the sample material chemically
- The adhesive shall be identifiable on the sample material
- The adhesive shall be removable from the sample material

### Concept

Pressure Sensitive Adhesive (PSA) is applied as a thin film on the substrate



*Work associated with the PSA was conducted by Dr. Timothy Long, Center For Adhesive And Sealant Science, Virginia Tech University*

# Surface Sampling System

## Commercially Available PSAs (1 of 2)

Three candidate commercially available acrylic PSAs were applied to various substrates

- Avery-Dennison: AS-2520 TR, AS-2520 LX, and DEV-3680

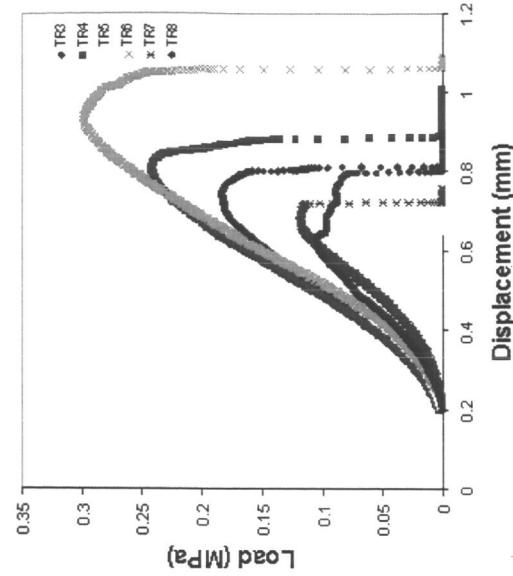
### Tack Testing

- Custom tack test designed based on ASTM D2979-01
- Tack testing conducted on two different PSAs and confirmed performance testing results
- TR is tackier than DEV

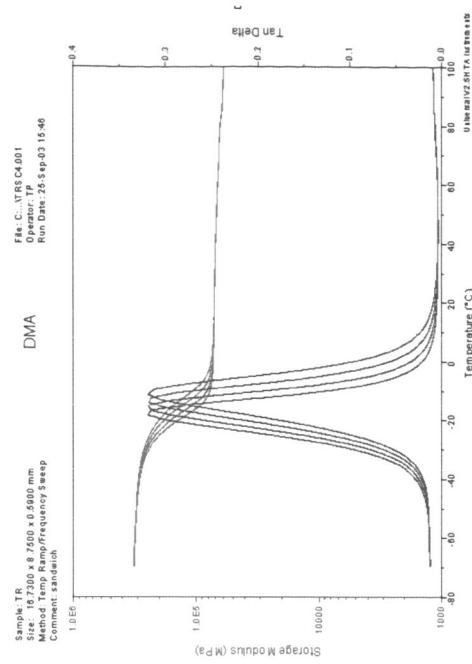
### Temperature Range

- Acrylic PSAs will have approximately 100°C to 150°C temperature range with minimum temperature > -50°C
- Composition can be tailored to desired range
- Target temperature range is -50°C to +50°C depending upon thermal analysis of target body

*Tack Test Results for AS-2520 TR*



*Thermal Properties for AS-2520 TR*



# Surface Sampling System

## Commercially Available PSAs (2 of 2)

### Presence of Adhesive on Sample

- PSAs have disadvantage of leaving a small amount of material on sample material after sampling and removal from pad
- Analyses shows that remaining adhesive is very localized and covers less than 5% of material surface

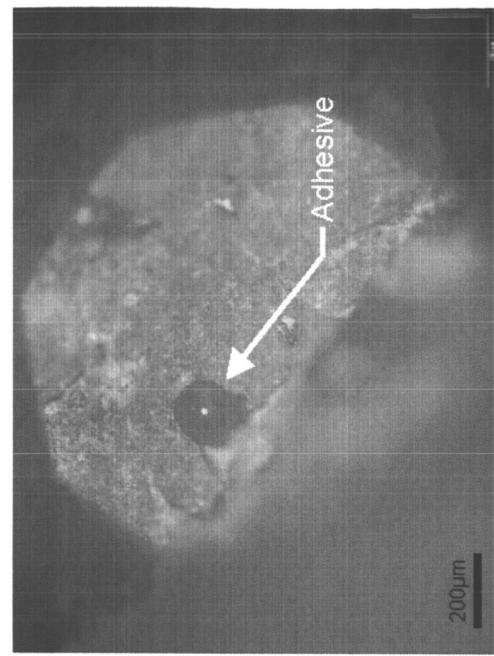
### Removal of Adhesive From Sample

- Developed a procedure to remove adhesive from sample material
- X-Ray Photoelectron Spectroscopy (XPS) results establish feasibility of removing all measurable amounts of adhesive from sample

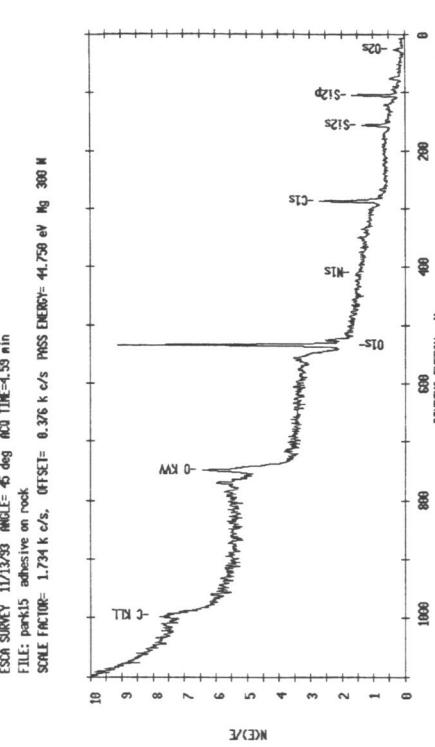
### Conclusion

- Of the three commercially available adhesives tested, AS-2520TR performed the best
  - AS-2520TR did not perform adequately at low temperatures
    - Based on low temperature sample collection tests conducted by SpaceWorks

### Image of Adhesive on Surface After Removal from Pad



### XPS Results For Adhesive Side of Particle



# Surface Sampling System

## Baseline Adhesive

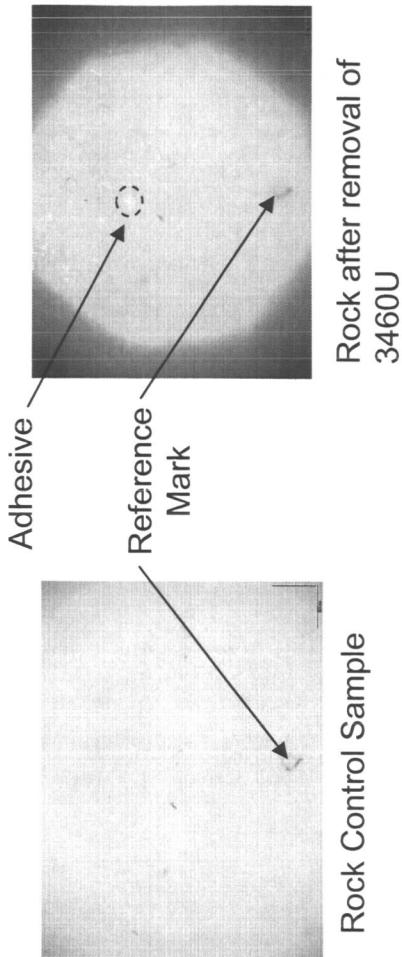
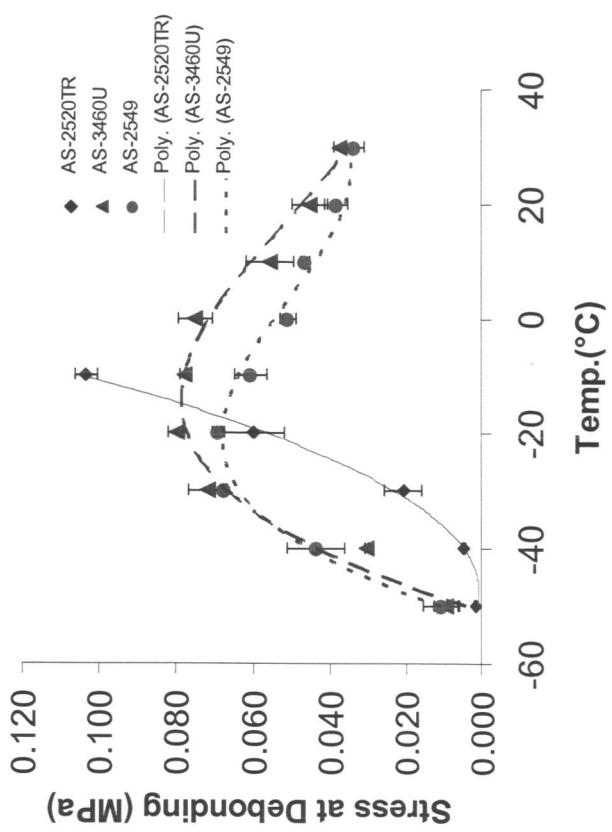
An untackified version of AS-2520TR was considered to increase performance at low temperatures

- AS-3460U is an untackified version of AS-2520TR
- Tests conducted by Virginia Tech show that AS-3460U will collect surface sample below - 40°C
- Outgassing: 0.24% TML, <0.01% CvCM per ASTM E-595
- Adhesive is identifiable on the sample and can be removed using solvent wash and sonification

### Conclusions

- Based on initial testing at Virginia Tech, overall performance of AS-3460U was superior to AS-2520TR, especially at low temperatures

**AS-3460U adhesive became the baseline adhesive for the surface sampling system**

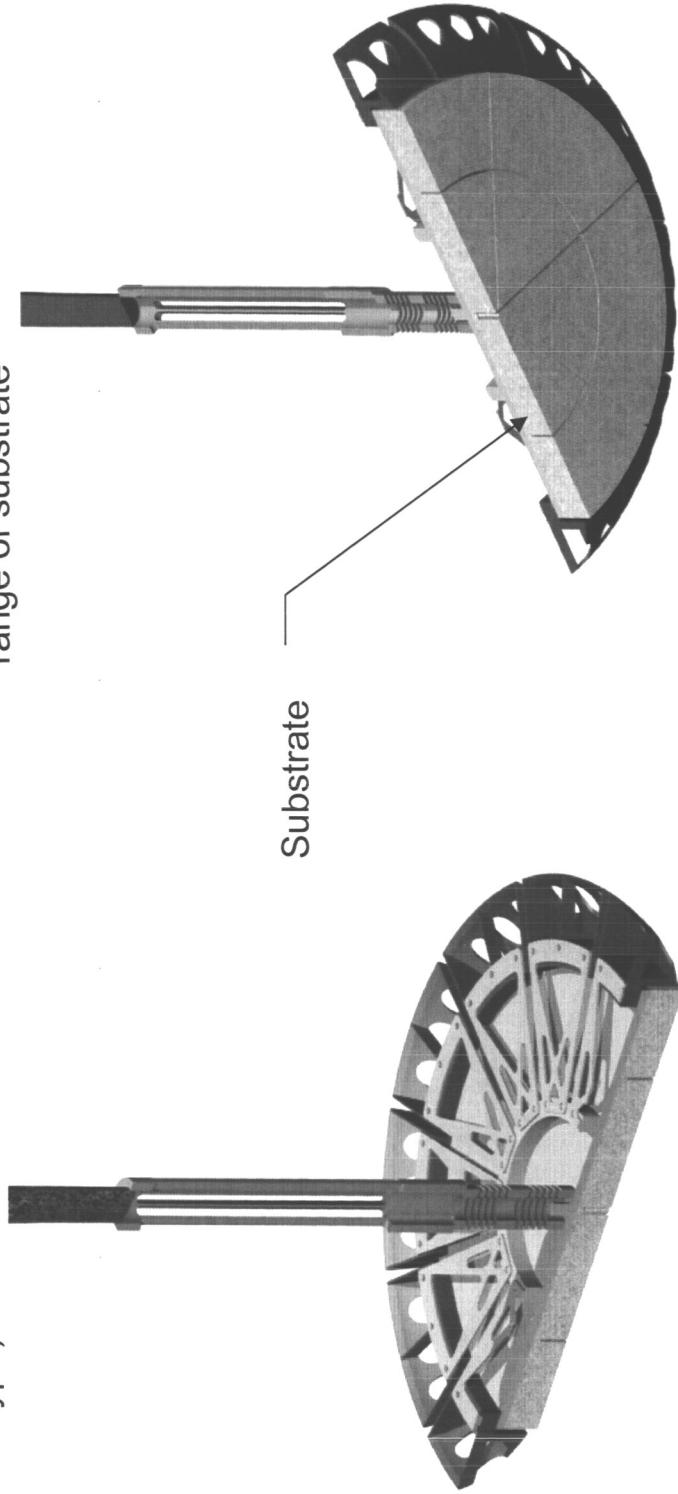


# Surface Sampling System

## Key Requirements

- Provide platform for adhesive that is conformable to particles from dust to 2.0 cm diameter
- Collect sample material in a way that does not crush, pulverize, or otherwise mechanically alter the sample material
- Collect sample material in a way that does not alter the chemistry of the material
- Collect sample material that is representative of the target surface (not favoring a particle size or type)
- Maximize the collection efficiency
- Preserve the location and orientation of the sample as it was on the target surface
- Maintain a surface area of  $929.03 \text{ cm}^2$  [144 in<sup>2</sup>] in contact with the target surface during sampling
- As a goal, substrate should collect and retrieve material from a depth of 1 cm below the target surface
- Sampling system not limited by temperature range of substrate

## Concept



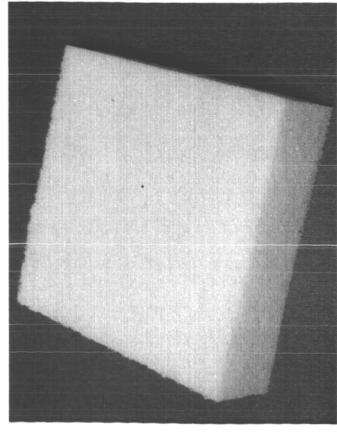
# **Surface Sampling System**

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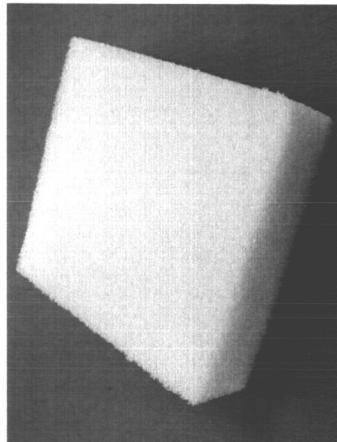
## **Substrate Candidates**

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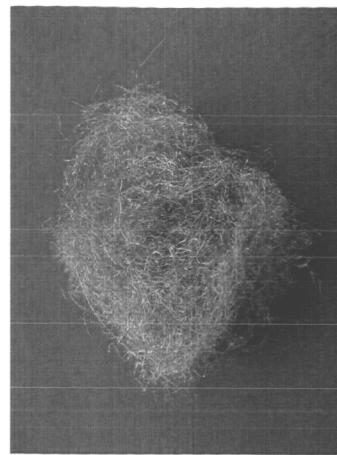
- SpaceWorks investigated more than 10 conformable substrates**
  - SpaceWorks conducted detail design engineering on those candidates



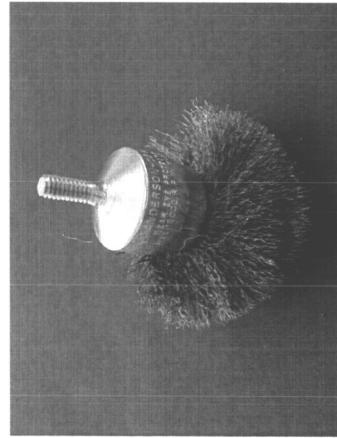
Confor Foam (polyurethane)



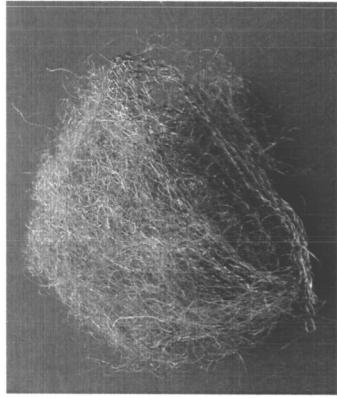
Soliimide Foam (polyimide)



Stainless Steel Wool



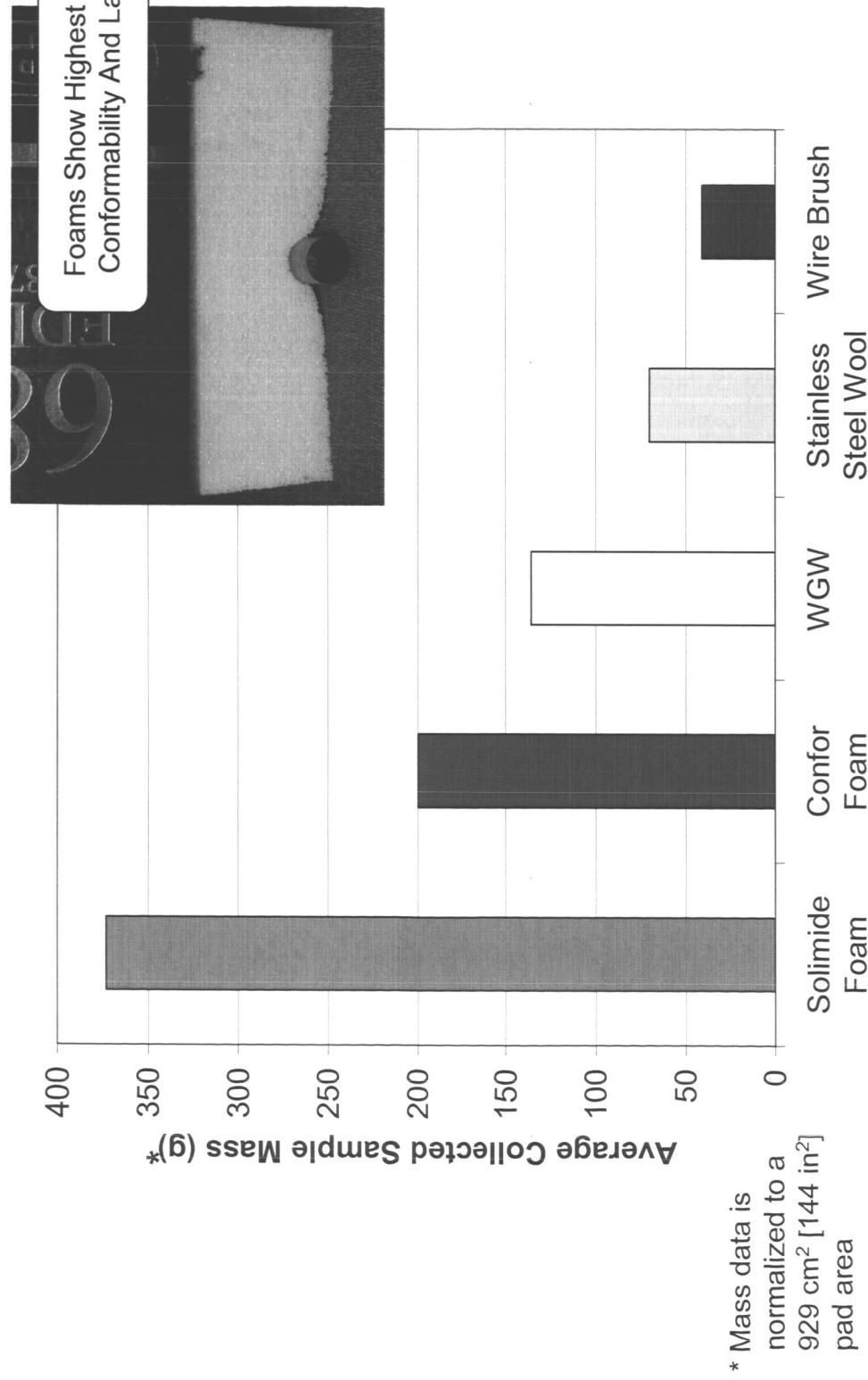
Wire Brush



Stainless Steel Wool/ Steel Gauze/ Stainless Steel Wool (WGW)

# Surface Sampling System

## Collection Efficiency



**Compared With All Of The Other Substrates Tested, Foams Were The Most Effective At Collecting Sample Material**



## Surface Sampling System

### Substrate Summary

Performance Characteristics	Confor Foam	Solimide Foam	Stainless Steel Wool	Wire Brush	Wool/Gauze/Wool
Outgassing (1.0% TML 0.1% CVCM)	1.07% TML 0.22% CVCM	0.2% TML 0.02% CVCM	0	0	0
Space Flight Heritage	N/A	MER, Shuttle	N/A	N/A	N/A
Conformability	Excellent	Excellent	Good	Poor	Good
Stratigraphy	Surface Only	Surface Only	Surface Only	0.25 cm depth	Surface Only
Mass/Area	0.22 g/cm <sup>2</sup>	0.40 g/cm <sup>2</sup>	0.08 g/cm <sup>2</sup>	0.04 g/cm <sup>2</sup>	0.15 g/cm <sup>2</sup>
Collected Mass	199.6 g	373.4 g	74.3 g	37.2 g	136.0 g
Temperature Range	10 to 49°C	-184 to 200°C	N/A	N/A	N/A
Particle Size (Powder to 2 cm dia.)	All	All	All	Powder to approx. 0.3 cm in dia.	All

**Solimide Was Selected For The Baseline Design Because Of Its Outgassing, Flight Heritage, And Temperature Range Characteristics**

# Surface Sampling System

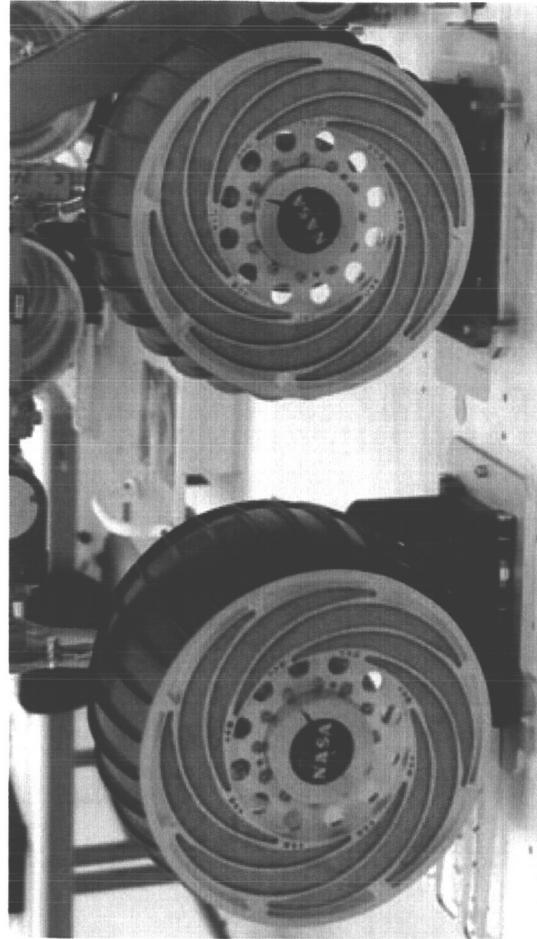
Produced by Inspec Foams

## Material Properties

- Polyimide Foam
- Low Outgassing
  - 0.2% Total Mass Loss (TML)
  - 0.02% Collected Volatile Condensable Material (CVCM)
- Temperature Range
  - -184 to 200°C

## Flight Heritage

- Mars Exploration Rover (MER)
  - Used inside of wheels
- Shuttle
- Expendable Launch Vehicles
  - Centaur, Ariane, Sea Launch
- Communications Satellites
- Space Station



This Up-close Photo Shows The Spiral Flectures Which Act As Shock Absorbers And The Orange Solimide That Fills The Flectures, Preventing Rocks And Debris From Interfering With The Driving And Steering Actuators

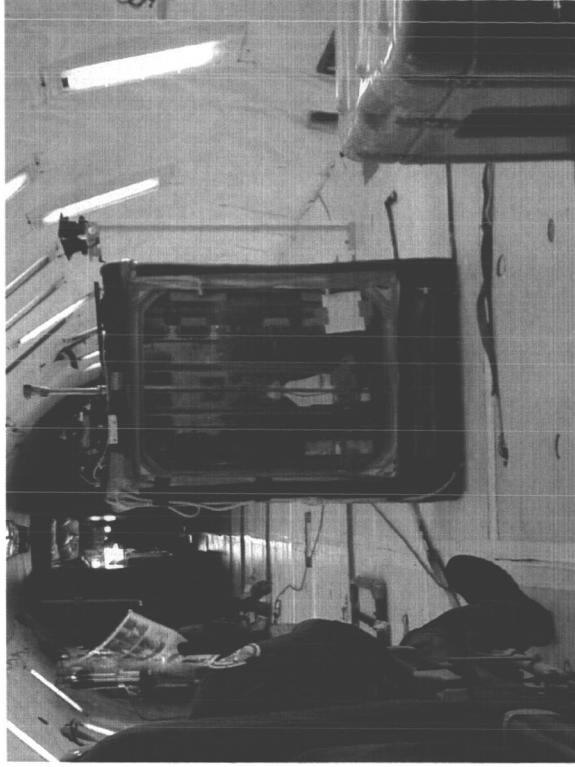
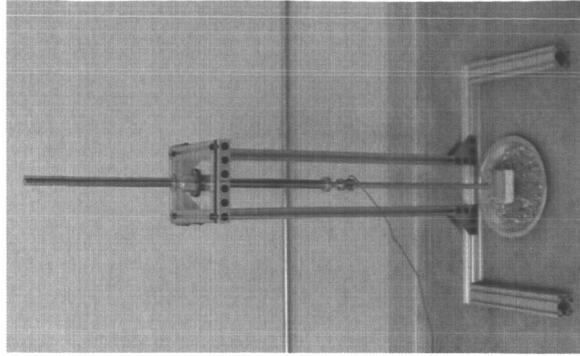
**Solimide Has Excellent Material Properties For This Application And Extensive Space Flight Heritage**

# Surface Sampling System

## Test Program Summary

### **SpaceWorks conducted over 100 initial substrate sample collection tests**

- Variety of contact force and time combinations
- Testing conducted in 1 g and microgravity conditions
- Sample material ranged in size from very fine sand to 1 cm particles
- Post flight tests eliminated lower performing substrates and added substrates that could increase sample depth



Adhesive	Confor Foam	Preflight Ground Tests			Stainless Steel Gauze	Total
		Wire Brush	Stainless Steel Wool	WGW		
LX	3	2	1	0	0	6
TR	7	2	3	2	1	15
DH	2	0	2	0	0	4
Total	12	4	6	2	1	25

Adhesive	Confor Foam	KC-135 Flight Tests			WGW	Total
		Wire Brush	Stainless Steel Wool	WGW		
TR	9	1	1	1	1	12
DH	11	0	2	3	3	16
Total	20	1	3	4	4	28

Adhesive	Solvimide Foam	Post Flight Ground Tests			Tube Array	Total
		Steel Pins	Tube Array	Total		
LX	0	0	0	0	0	0
TR	36	1	1	1	38	38
DH	0	0	0	0	0	0
Total	36	1	1	1	38	38

# Surface Sampling System

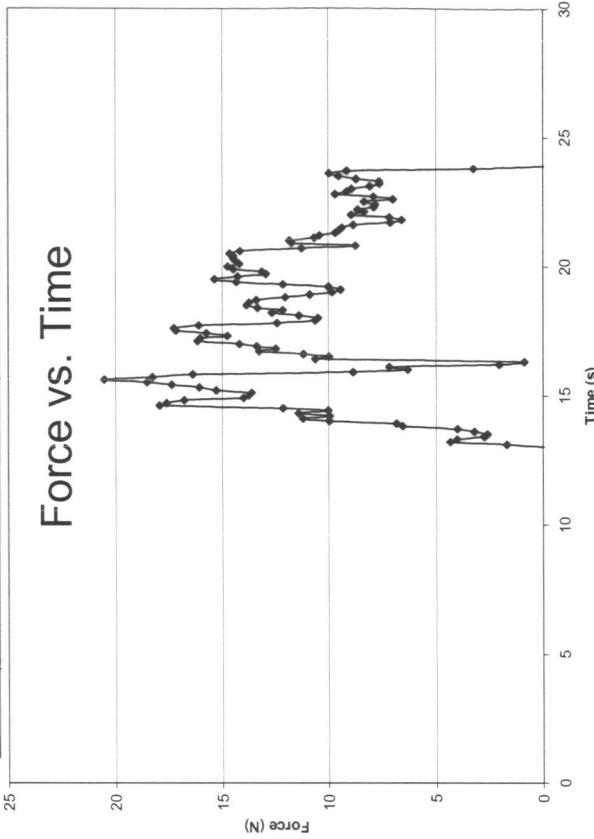
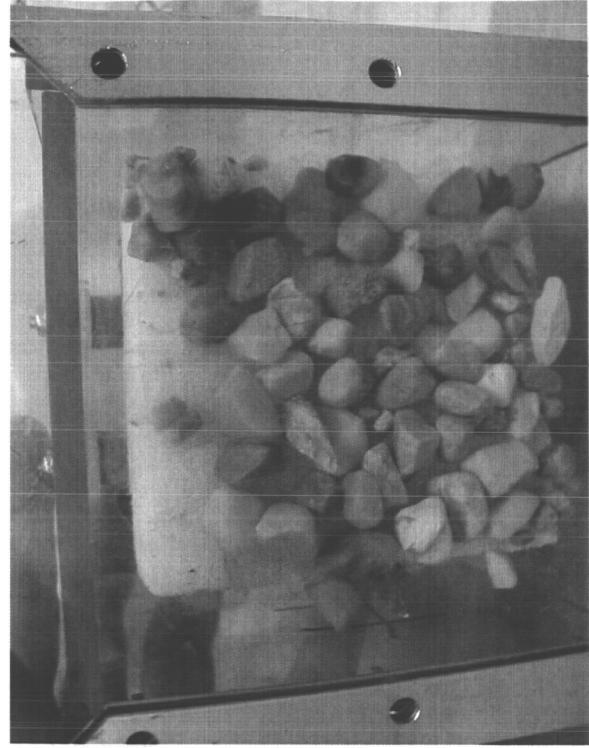
## Sample Flight Test Results

Example Of Data Collected For Each Of The 28 Sampling Events During The KC-135 Tests

Description	Value
Flight No.	2
Date	7/30/2003
Sample Box No.	4
Sample Order No.	5
Adhesive Pad ID	F22
Substrate Material	Polyurethane Foam
Adhesive	TR
Footprint (cm <sup>2</sup> )	58.1
Force (N)	5.0
Target Duration (s)	10.0
Impulse (N-s)	50.0
Force (N)	11.1
Actual Duration (s)	10.9
Impulse (N-s)	119.4
Initial Mass (g)	22.9
Final Mass (g)	77.1
Sample Collected (g)	54.2
Mass (g)	54.2
Total Mass	100.0
Percentage (%)	100.0
Sample mass/ substrate mass	2.37
Sample mass/ contact area (g/cm <sup>2</sup> )	0.93

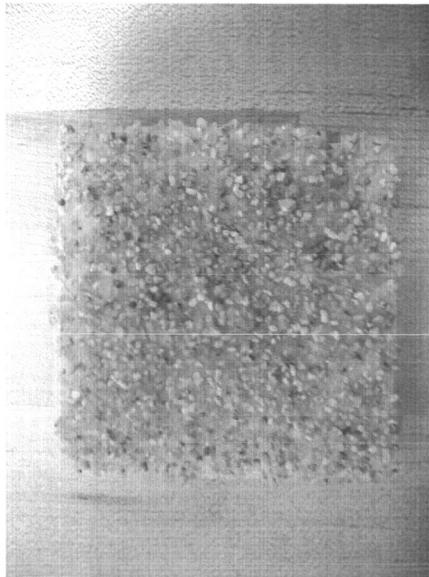
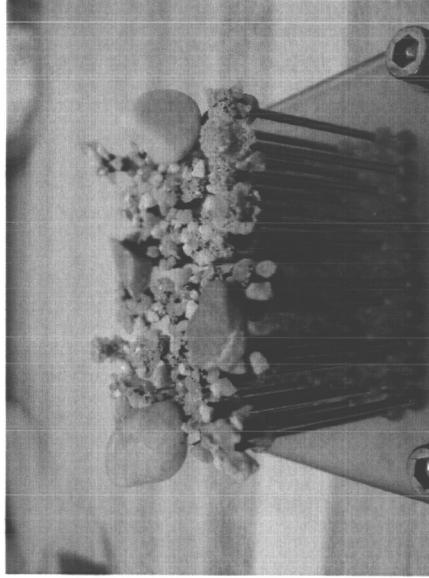
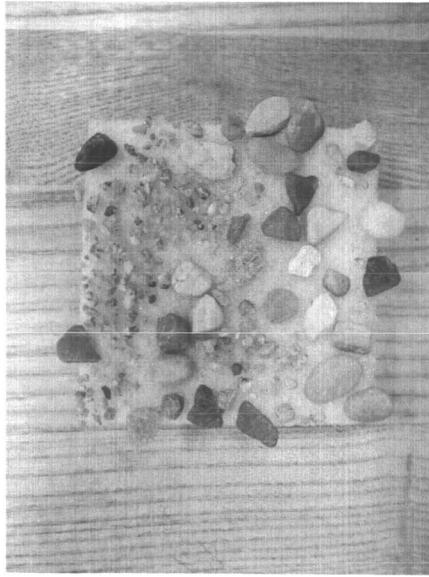
### Video Observations:

- Small amount of sample material adhered to sample pad as a result of a negative g prior to the sample event
- Pad may have been in contact with sample material prior to sample event
- Large negative g after sample event



# **Surface Sampling System**

## ***Flight Test Substrate Photographs***

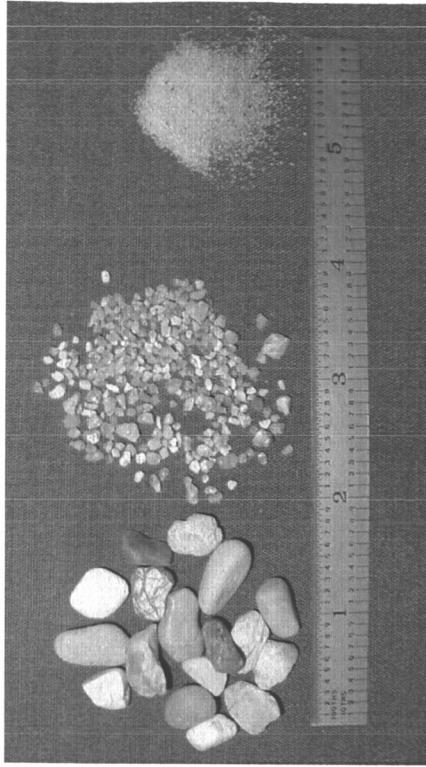


# Surface Sampling System

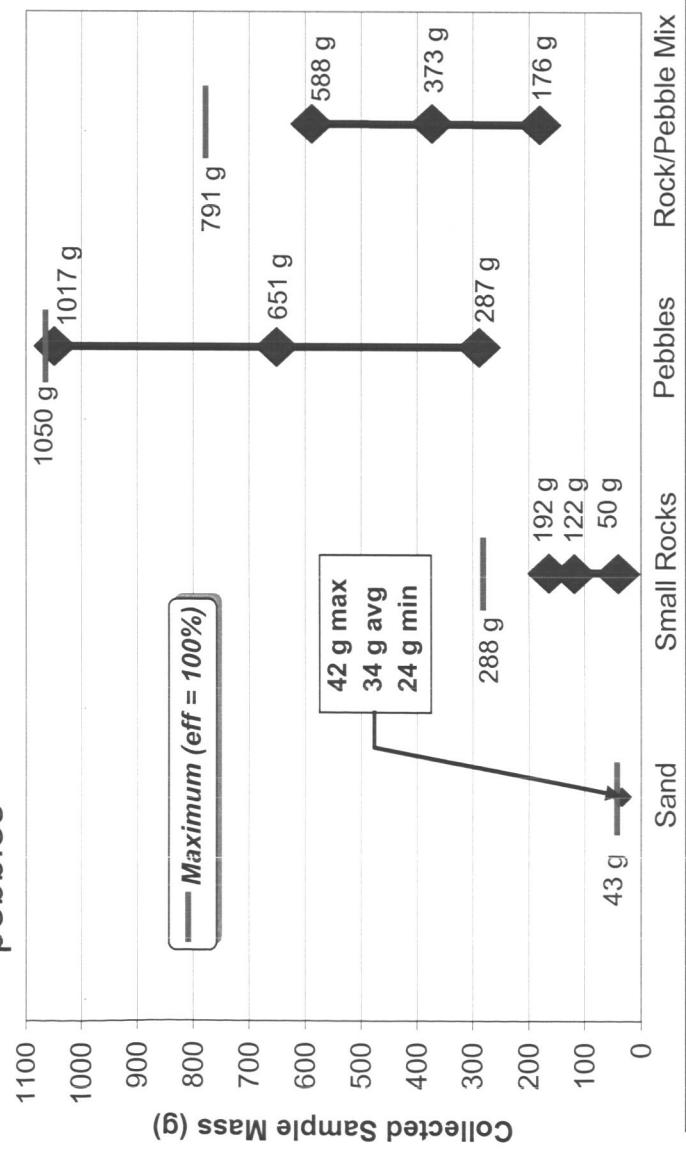
## Flight Test Collected Particle Size

The baseline solimide/PSA design achieves comparable collection efficiencies over the widest material range

- Adhesive = AS-2520 TR
- Substrate = Solimide Foam
- Force Range = 2.5 - 40 N
- Sample Time 1 – 10 s
- Tests conducted on sand, small rocks, pebbles, and a mixture of small rocks and pebbles



*From left to right: pebbles, small rocks, fine sand*

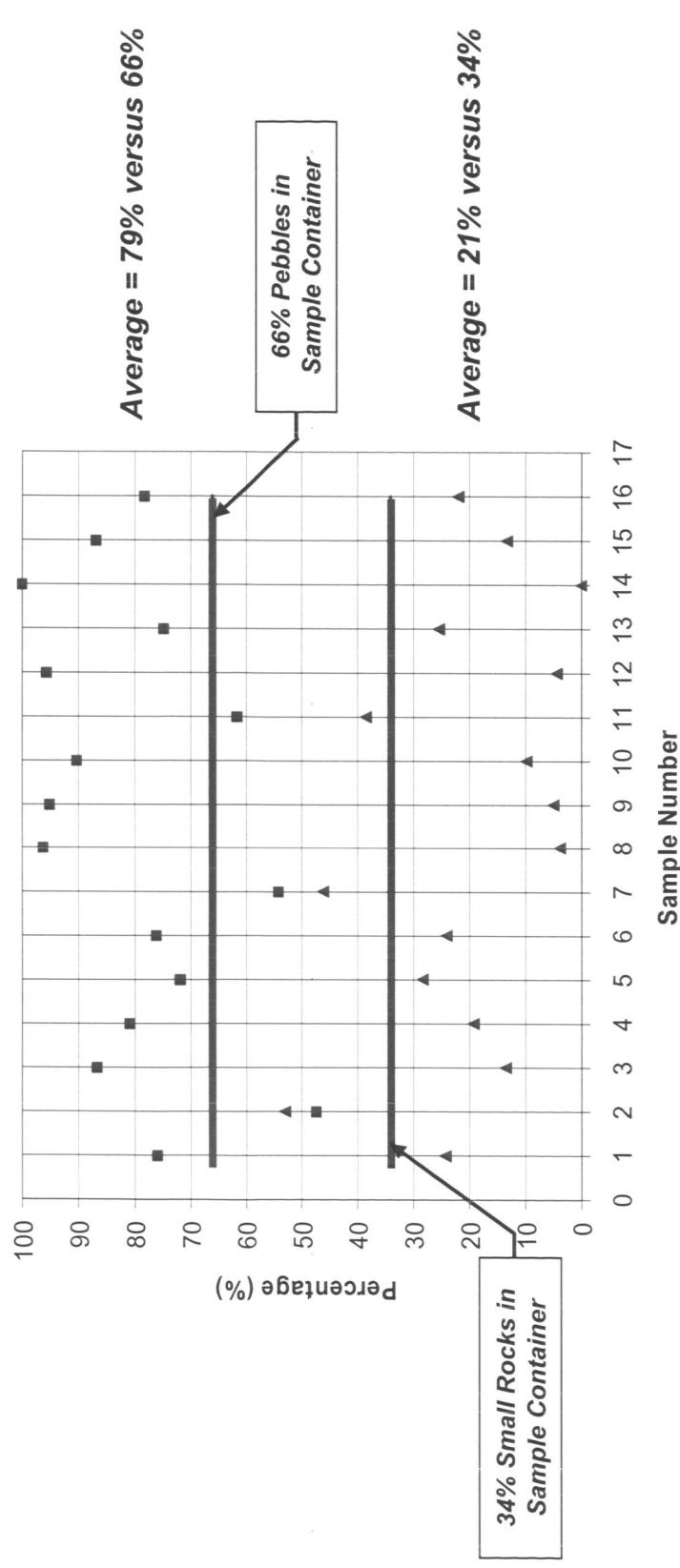


## **Surface Sampling System**

### **Particle Discrimination**

**Test results suggest that the baseline design collects a representative sample**

*Flight 3 And Solimide Ground Testing Sample Material Consisting Of Sand And Pebbles*

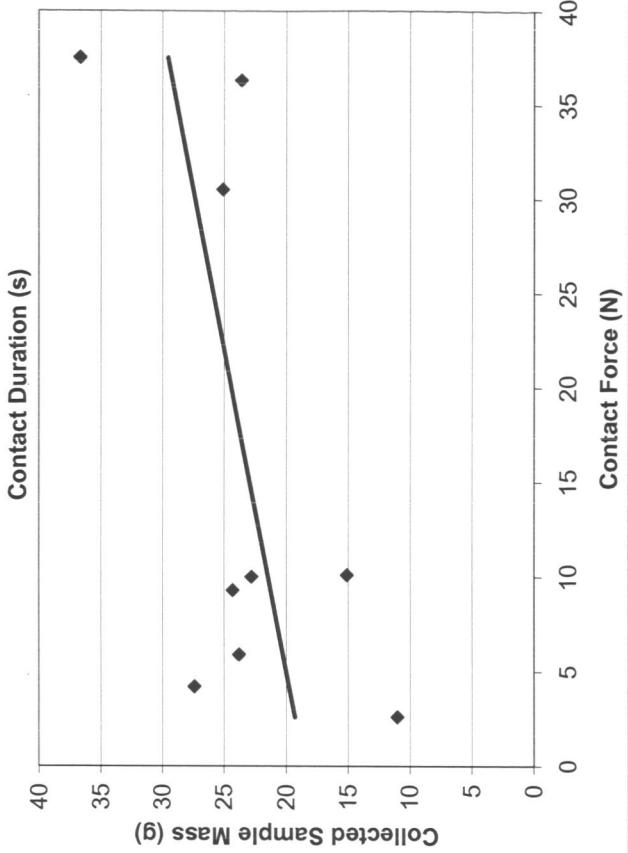
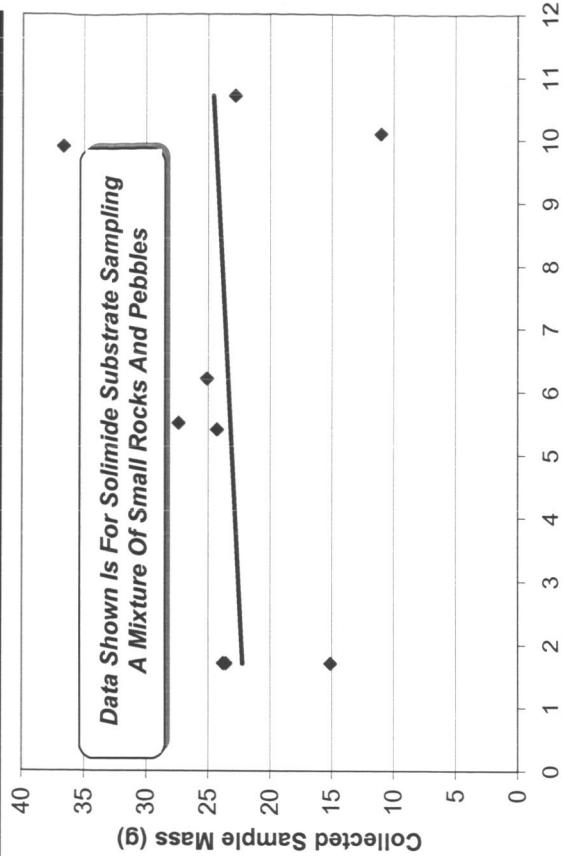


# Surface Sampling System

## Sampling Force and Time

The baseline design can be operated over a wide range of force and time

- Efficiency appears to be insensitive to contact duration
  - 1-10+ seconds is acceptable
- Efficiency appears to be a weak function of force
  - 10-40+ N is acceptable



## **Surface Sampling System**

### ***Low Temperature Sample Collection Overview***

**Sample material was collected by the baseline substrate/adhesive pad to demonstrate performance of the baseline substrate and adhesive at low temperatures**

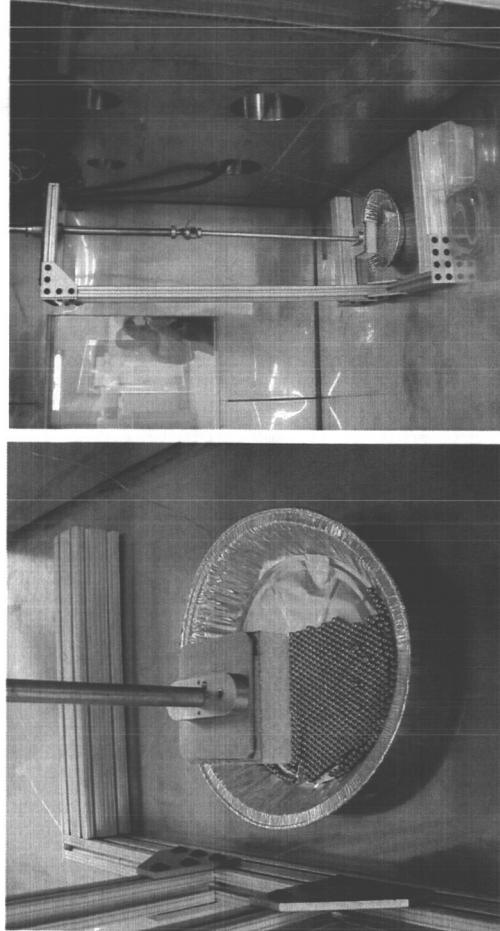
- Adhesive: AS-2520TR
- Substrate: 3 X 3 in. Solimide pads coated with adhesive
- Sample material: Zinc coated steel Ø.177 in. diameter ball bearings and small pebbles approximately 0.1 - 0.2 in. in diameter.
- Sample Force:
- Sample Duration:
- Environmental Tests consisted of the following tests:
  - Cold Sample, Cold Pad – simulates an unheated adhesive sampling pad collecting sample from a cold body
  - Cold Sample, Warm Pad – simulates a heated adhesive sampling pad collecting sample from a cold body
  - Survival Temperature – ensures that an adhesive sampling pad exposed to -100°C can still collect surface sample
- Tests were conducted at Dynamic Labs in Phoenix, AZ on September 20<sup>th</sup> – 22<sup>nd</sup>, 2004

# Surface Sampling System

## Cold Sample/Cold Pad Test

### Test stand, sample material, and adhesive pads were placed in thermal chamber

- Temperature of sample material and adhesive pads were monitored
- Temperature range: +25°C to -30°C
- Sample material consisted of Ø.177 in. steel ball bearings and small pebbles



### Results

- -25°C was the lowest temperature where sample material was collected
  - 3.7g of sample material collected
  - Sample force was increased to 8.5 lbs to collect sample at this temperature

Cold Sample/Cold Pad Results Summary				
Temperature (°C)	Average Collected Mass (g)	Std Dev.	Force (lb)	Sample Material
+25	108.0	7.1	3.5	Steel
0	83.5	8.1	3.5	Steel
-10	60.0	3.6	3.5	Steel
-20	25.7	8.1	4.5	Steel
-20	1.3	1.8	4.5	Pebbles
-23	0.0	N/A	4.5	Steel
-23	0.7	N/A	8.5	Pebbles
-25	20.0	28.3	4.5	Steel
-25	0.0	N/A	4.5	Pebbles
-25	1.8	3.7	8.5	Steel
-25	0.2	0.4	8.5	Pebbles
-26	0.0	0.0	8.5	Pebbles
-27	0.0	N/A	8.5	Pebbles
-30	0.0	0.0	4.5	Steel

# **Surface Sampling System**

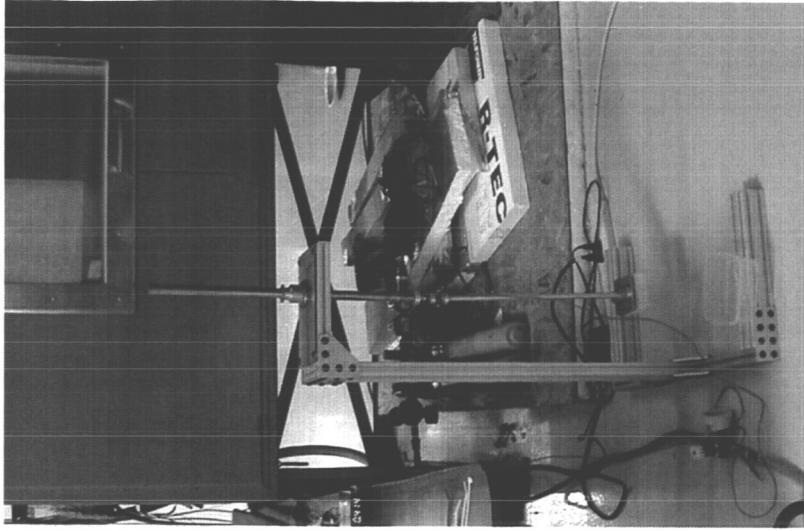
## **Cold Sample/ Warm Pad**

**Sample material was allowed to cool in thermal chamber while adhesive pads were kept at room temperature**

- Temperature of sample material was monitored
- Sample material consisted of Ø.177 in. steel bearings only
- Sample temperature range: 0°C to -30°C

## **Results**

- -24°C was the lowest temperature at which sample material was collected
  - 6.7 g (3.5 lb sampling force) and 10.4g (4.5 lb sampling force)



Cold Sample/Warm Pad Results Summary				
Temperature (°C)	Average Collected Mass (g)	Std Dev.	Force (lb)	Sample Material
0	75.2	16.474	3.5	Steel
-10	64.2	12.423	3.5	Steel
-20	15.5	8.568	3.5	Steel
-23	6.3	2.281	3.5	Steel
-24	6.7	3.522	3.5	Steel
-24	10.4	4.210	4.5	Steel
-25	0	0.000	4.5	Steel
-30	0	0.000	4.5	Steel

# Surface Sampling System

## Survival Temperature

---

**Adhesive pads were cooled to -100°C in an environmental chamber**

- Nitrogen purge thermal chamber
- Adhesive pad temperature was monitored

**Adhesive pads were then allowed to warm to room temperature**

- Adhesive pad temperature was monitored

**Adhesive pads collected sample material**

- Room temperature steel ball bearing sample material
- Sampling Force: 3.5 lbs

## Results

- Adhesive pads collected an average of 80.6 g of sample material

Sample Number	Sampling Temperature (°C)	Survival Temperature				
		Mass of Pad (g)	Mass of Pad and Adhesive w/o Sample (g)	Mass of Pad w/ Sample (g)	Mass of Sample (g)	Force (lbs)
61	25	1.0	3.7	94.8	91.1	3.5
62	25	1.0	4.0	97.7	93.7	3.5
63	25	1.1	4.1	61.0	56.9	3.5

# Surface Sampling System

## Low Temperature Sample Collection Conclusions

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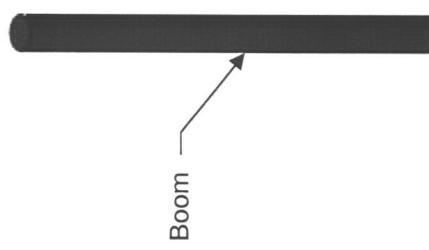
### Conclusions

- An increased sampling force is required to obtain a sample when the sample material temperature is lower than -20°C and a cold adhesive pad (also lower than -20°C) is used.
- The mass of samples collected in the cold sample/cold pad test were higher for the Ø.177 in. steel spheres than for the pebbles because of the uniformity of the steel spheres and the higher density of the steel as compared to the pebbles.
- The ability of the adhesive to collect sample material gradually decreases until -25°C. Below -25°C, no sample material can be easily collected using the current pad and adhesive.
- The use of a warm pad versus a cold pad did not significantly increase the ability of the adhesive to collect additional sample material. The warm pad did allow a lower sampling force to collect sample in the -20°C to -25°C range.
- The adhesive is not affected by exposure to temperatures as low as -100°C.

# Surface Sampling System

## Surface Sampling System

- Simple design
- Passive sample collection method
- Requires no power to operate
- Retains relative particle position information
- Does not alter the collected sample physically or chemically



## Sampler System Overview

### Size and Mass

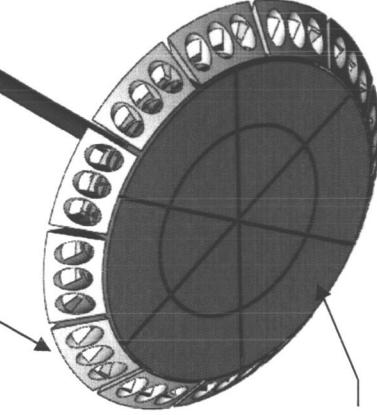
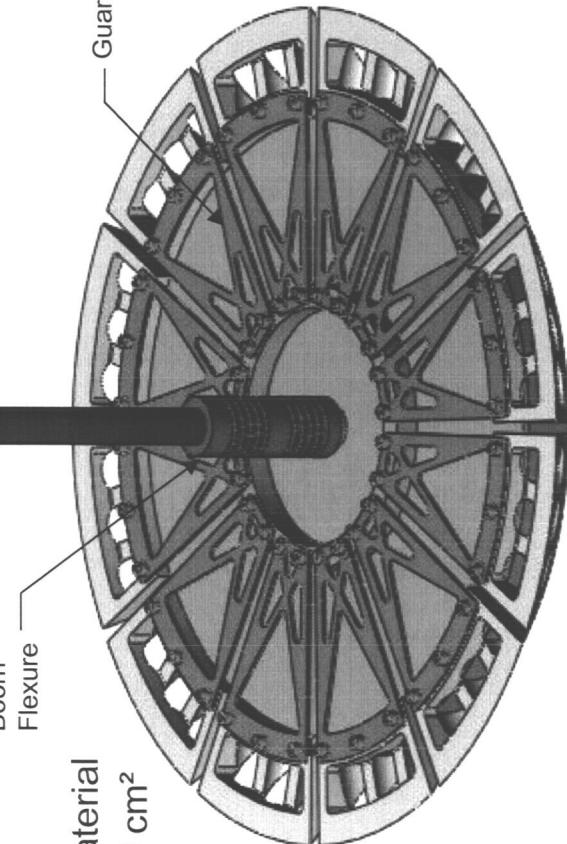
- Ø 43.9 cm [17.3 in.]
- Height: 57.5 cm [22.625 in.]
- 929 cm<sup>2</sup> [144 in<sup>2</sup>] sampling area
- Mass CBE: 2.26 kg [4.98 lbs]
  - Includes boom and boom flexure

### Materials

- All materials are low-outgassing
- Solimide foam substrate
  - Acrylic pressure sensitive adhesive
- Edge Guard
- Adhesive Pad

### Solimide Foam Substrate

- Conformable foam
- Space qualified material
- Surface Area: 929 cm<sup>2</sup>



# Surface Sampling System

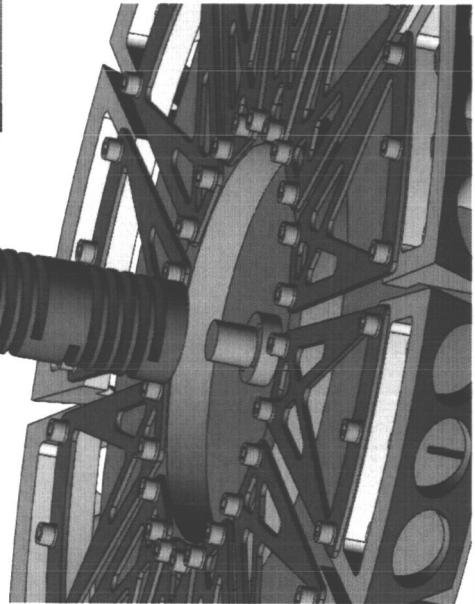
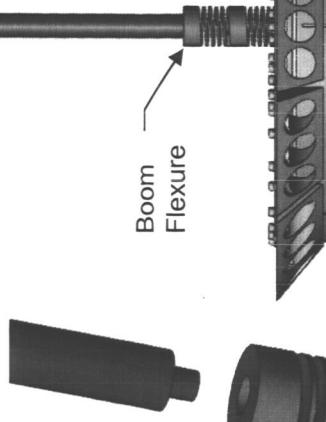
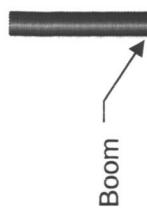
## *Flexure and Boom*

### Boom

- Material: Aluminum 6061
- Boom is representative of what a flight boom might look like

### Boom Flexure

- Helical beam coupling
  - 10° of flexure
- Interfaces with sampler head and boom using integral clamp collars

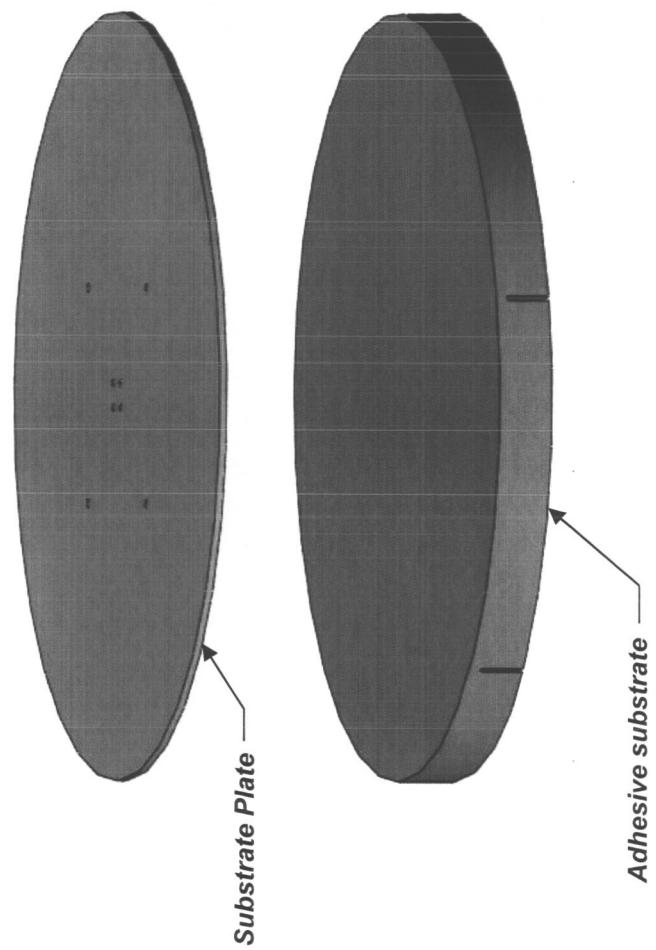


# Surface Sampling System

## **Substrate Plate**

### **Adhesive substrate attaches to substrate plate**

- Provides structure to adhesive pad and interface to boom assembly
- Substrate plate material is Delrin
- Same diameter as adhesive pad
  - Ø 34.42 cm X 0.32 cm [13.550 in. X .125 in.]



### **Adhesive pad to substrate plate interface**

- Adhesive substrate is bonded to substrate plate with 3M 2216 epoxy

## Surface Sampling System

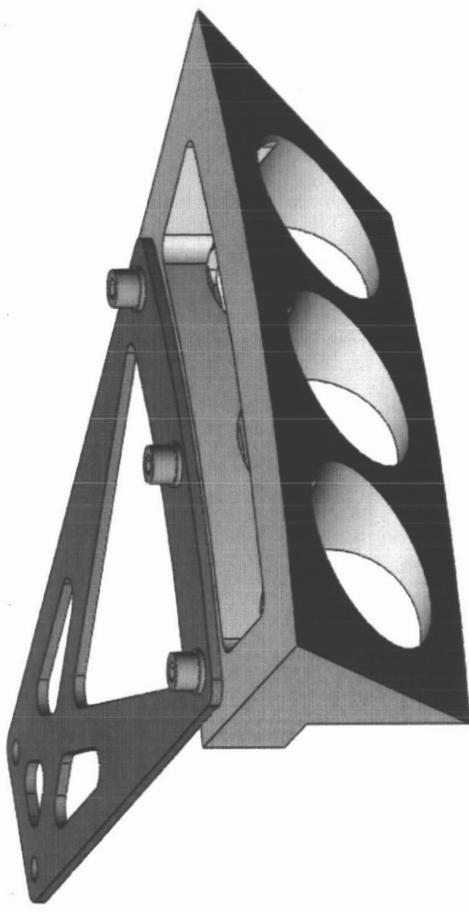
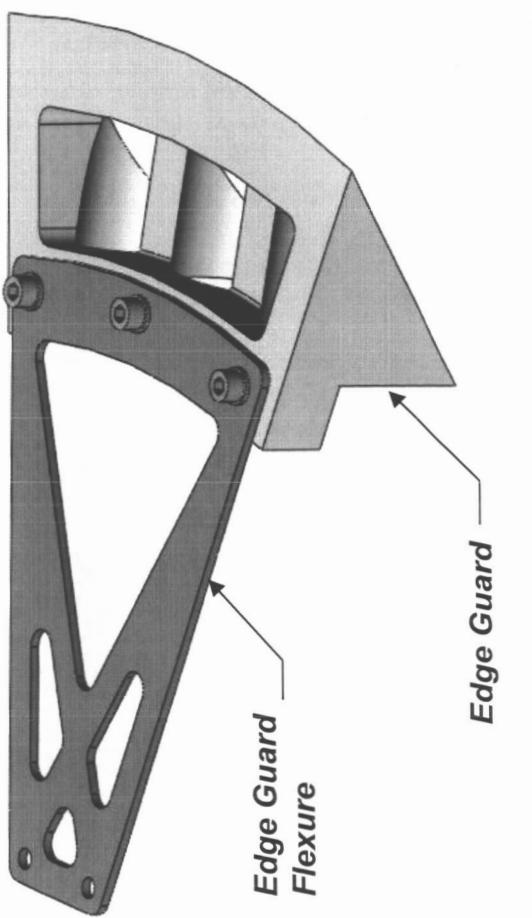
### Edge Guards and Edge Guard Flexure

#### Edge guards protect the substrate from a side impact

- Edge guards “flex” to expose adhesive substrate
- Edge guard material is Delrin

#### Deflection

- Edge guards will deflect .100 in. under 1.0 lb load
- Flexure material is carbon fiber composite woven prepeg
  - ZMR705 12K



# Surface Sampling System

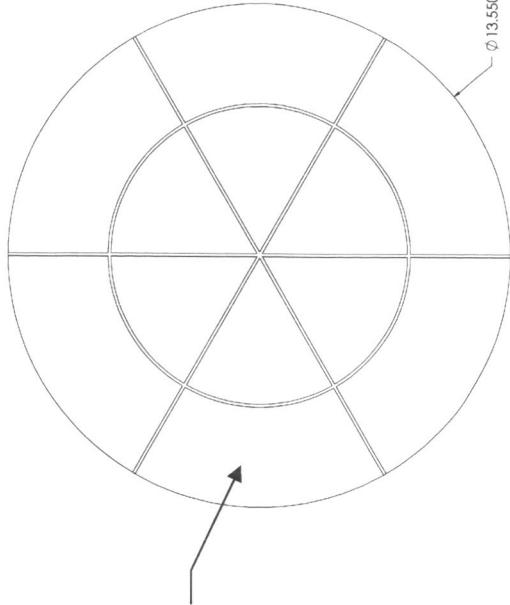
## Substrate

- Substrate is Solimide foam
- Cylindrical geometry
- Contact Surface Area:  $929 \text{ cm}^2$   
[ $144 \text{ in}^2$ ]

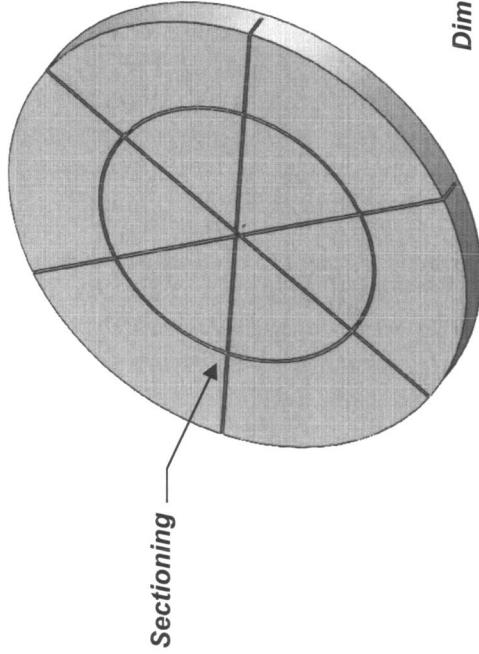
## Material Properties

- Polyimide Foam
- Low Outgassing
  - 0.2% Total Mass Loss (TML)
  - 0.02% Collected Volatile Condensable Material (CVCM)
- Temperature Range
  - -184 to 200°C

**Conformability of the substrate will be enhanced by sectioning the contact surface**



Contact  
Area:  $144 \text{ in}^2$



Sectioning

Dimensions: *in.*

## Surface Sampling System

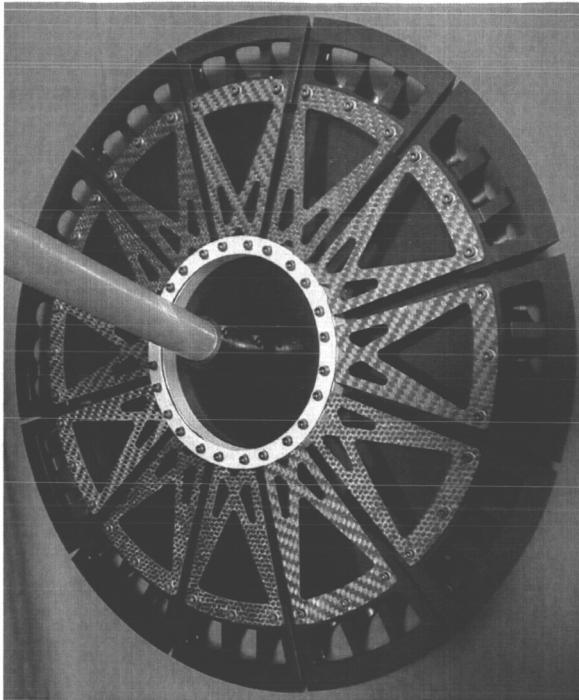
- | Mass               | Component          | Mass (g) | Quantity | Total Mass (g) |
|--------------------|--------------------|----------|----------|----------------|
| Substrate          | Substrate          | 14.7     | 1        | 14.7           |
| Substrate Plate    | Substrate Plate    | 416.0    | 1        | 416.0          |
| Edge Guard         | Edge Guard         | 56.9     | 12       | 682.8          |
| Edge Guard Flexure | Edge Guard Flexure | 46.1     | 12       | 553.2          |
| Boom Flange        | Boom Flange        | 9.5      | 1        | 9.5            |
| Interface Ring     | Interface Ring     | 157.1    | 1        | 157.1          |
| Retaining Ring     | Retaining Ring     | 19.7     | 1        | 19.7           |
| Boom               | Boom               | 355.0    | 1        | 355.0          |
| Boom Flexure       | Boom Flexure       | 12.0     | 1        | 12.0           |
| Fasteners          | Fasteners          | 40.0     | -        | 40.0           |
|                    | Total (g)          |          |          | <b>2260</b>    |
| NTE Mass           |                    |          |          | 3500.0         |
| Margin             |                    |          |          | 1240.0         |
- CBE Mass: 2.260 kg [4.98 lbs]  
• NTE Mass: 3.500 kg  
• Margin: 1.240 kg

**Mass estimate does not include the adhesive, or 3M 2216 epoxy**

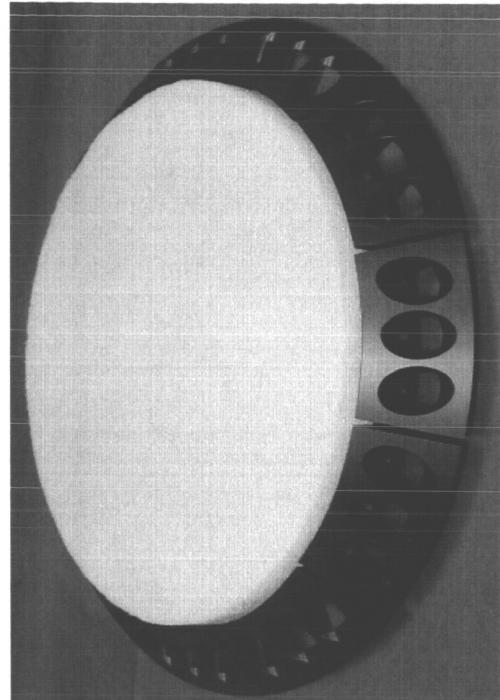
Mass	Component	Mass (g)	Quantity	Total Mass (g)
Substrate	Substrate	14.7	1	14.7
Substrate Plate	Substrate Plate	416.0	1	416.0
Edge Guard	Edge Guard	56.9	12	682.8
Edge Guard Flexure	Edge Guard Flexure	46.1	12	553.2
Boom Flange	Boom Flange	9.5	1	9.5
Interface Ring	Interface Ring	157.1	1	157.1
Retaining Ring	Retaining Ring	19.7	1	19.7
Boom	Boom	355.0	1	355.0
Boom Flexure	Boom Flexure	12.0	1	12.0
Fasteners	Fasteners	40.0	-	40.0
	Total (g)			<b>2260</b>
NTE Mass				3500.0
Margin				1240.0

## **Surface Sampling System**

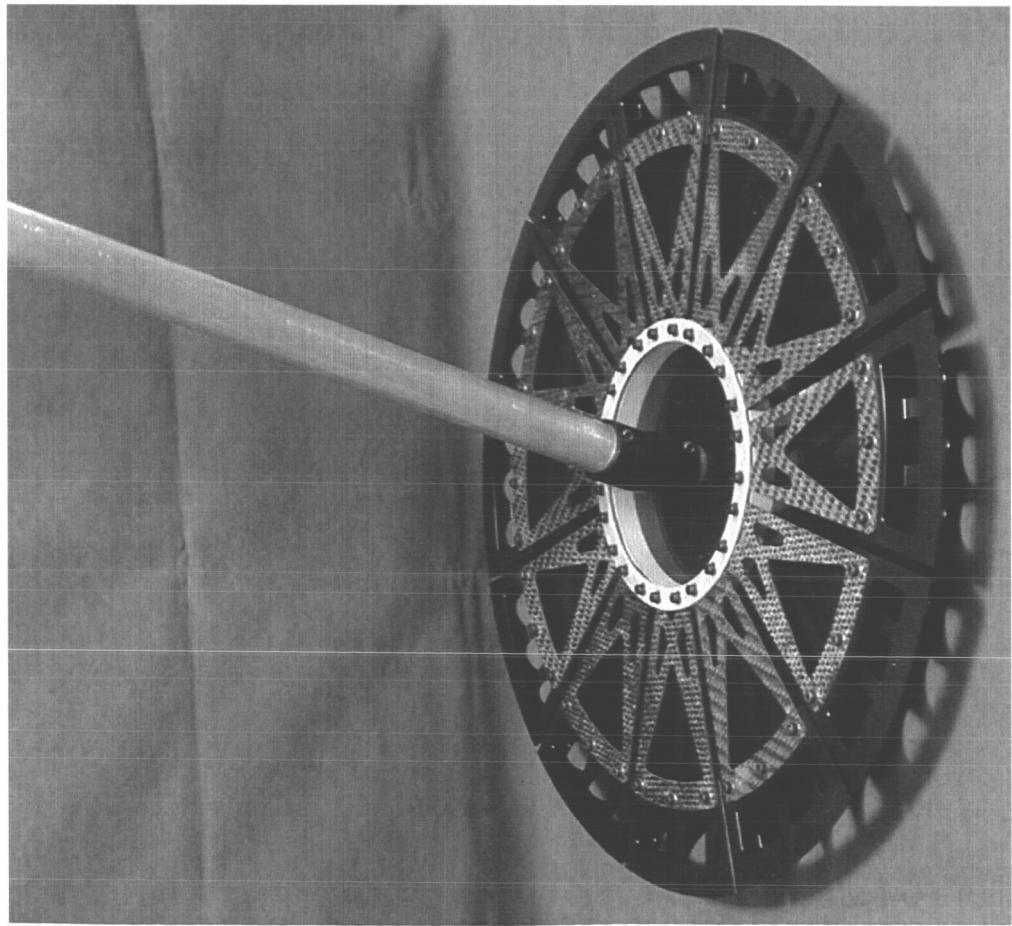
### **Sampler Hardware Pictures**



**Sampler Head (Top View)**



**Sampler Head (Bottom View)**



**Prototype Surface Sampler System**

# **Surface Sampling System**

## **Summary**

- SpaceWorks has identified several sampling missions that could benefit from the technology developed under this project
- Requirements were established for the surface sampling system
- SpaceWorks teamed with Virginia Tech to identify and select a baseline adhesive suitable for the surface sampling system
  - Avery Dennison AS-3460U was selected as the baseline adhesive
- SpaceWorks identified Solimide foam as the baseline substrate material
- SpaceWorks conducted extensive testing to characterize the performance of the substrate/adhesive combination
- A prototype version of the sampler head was designed and built by SpaceWorks

## **Summary**

## **Surface Sampling System**

## ***Contact Information***

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